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Are Returns to Mothers' Human Capital Realized in the Next Generation?

The Impact of Mothers' Intellectual Human Capital and Long-Run Nutritional Status on Children's Human Capital in Guatemala

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ABSTRACT

Many prior studies find significant cross-sectional positive ordinary least squares (OLS) associations between maternal human capital (usually maternal schooling attainment) and children's human capital (usually children's schooling, but in some cases children's nutritional status). This paper uses rich Guatemalan longitudinal data collected over 35 years to explore several limitations of these "standard" estimates. The preferred estimates developed herein suggest that (1) maternal human capital is more important than suggested by the standard estimates; (2) maternal cognitive skills have a greater impact than maternal schooling attainment on children's biological human capital; and (3) for some important indicators of children's human capital, maternal biological capital has larger effect sizes than maternal intellectual capital (schooling and cognitive skills). These results imply that breaking the intergenerational transmission of poverty, malnutrition, and intellectual deprivation through investments in women's human capital may be more effective than previously suggested, but it will require approaches that account for dimensions of women's human capital beyond just their schooling. Effective interventions to improve women's biological and intellectual human capital often begin in utero or in early childhood; thus, their realization will take longer than if more schooling were the only relevant channel.

Keywords: maternal human capital, cognitive skills, nutritional status, child outcomes, Guatemala

1. INTRODUCTION

Investments in women's human capital are often justified based on their presumed large positive effects on the next generation. In support of this, a number of influential scholars and policymakers argue that the effect of maternal human capital on children's health and education is large and causal in poor settings (e.g., Summers 1992, 1994; Stern 2001; World Bank 2001). However, at least five potentially important limitations pervade most of this literature.

First, attention has been focused almost entirely on the impact of maternal *intellectual* human capital, with the possible impacts of maternal *biological* human capital being largely ignored.[1] *Second*, schooling attainment is the most commonly utilized measure of women's intellectual human capital in these studies. However, schooling attainment should be seen as an input into women's knowledge, rather than its complete representation, due to variations in schooling quality and the out-of-school experiences that enhance learning throughout women's lives.[2] *Third*, women's human capital is almost always treated as if it were randomly assigned rather than being an outcome of behavioral decisions in the presence of intergenerationally-correlated endowments, such as genetics and preferences.[3] *Fourth*, indicators of women's human capital are generally treated as if they are perfectly measured and not affected by random noise. *Fifth*, most previous studies focus on just one type of children's human-capital outcome. The largest share of prior studies focus on one or a few outcomes related to children's intellectual development (e.g., schooling enrollment or attainment), while a sizable minority focuses only on indicators of children's biological development (e.g., birth weight and/or anthropometric measures of children's growth). This segregation of children's outcomes in the literature may mask potentially differential effects of maternal human capital on different types of children's human capital (e.g., the particularly strong effects of maternal intellectual human capital on children's intellectual human capital, and of maternal biological human capital on children's biological human capital).[4]

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[1] Evidence continues to accumulate suggesting that long-run nutritional status, determined in considerable part by early-life nutrition (which, in turn, is affected by nutrient intake, infectious disease experience, and stimulation), has a long-run impact on cognitive skills and productivities in poor societies (e.g., Behrman et al. 2005, 2008; Engle et al. 2007; Hoddinott et al. 2008; Maluccio et al. 2009; Martorell 1997; Strauss and Thomas 1998; Victora et al. 2008).

[2] Behrman et al. (2008), using the same data set utilized for the present study, estimate cognitive skill production functions for adult reading comprehension and nonverbal skills. If ordinary least squares (OLS) estimates are made using a specification in which the only input into these production functions is schooling attainment, the coefficient estimates of schooling are large and highly significant. If preschool and post-school experiences are included in addition to schooling, and all of these experiences (including schooling) are treated as behaviorally-determined with instrumental variable estimates, the coefficient estimate for schooling attainment is about half as large but still significant for reading comprehension scores, but insignificant for nonverbal skills. Thus, in the OLS estimates including only schooling, schooling apparently proxies substantially for pre- and post-schooling experiences and unobserved endowments such as innate ability.

[3] A small subset of articles, primarily recent studies in developed countries, have investigated what happens to estimates of impacts of maternal schooling attainment on child outcomes if maternal human capital is behaviorally determined within a life-cycle framework that accounts for unobservables, such as innate ability and health, using identical twin data (Behrman and Rosenzweig 2002, 2005), adoption data (Plug and Vijverberg 2003; Plug 2004), and instrumental variable estimates (Black, Devereux, and Salvanes 2005; Carneiro, Meghir, and Parey 2007), based on phased-in changes in compulsory schooling or local tuition fees, distance to college, and local labor market variables as instruments. We are aware of only two articles for developing countries that investigate changes in the estimated impact of mothers' schooling on child schooling or health when the mothers' schooling is also treated as endogenous, using within-adult sister data to control for the common genetic and parental/family environments (Behrman and Wolfe 1987a, 1987b). All of these studies report some substantial changes, usually reductions, in the estimated impacts of maternal schooling attainment when alternative means are used to control for unobserved endowments. We are not aware of studies investigating what happens if maternal long-run nutritional status is also treated as endogenous for determining children's human capital.

[4] We know of a few articles that include indicators of both types of children's human capital (e.g., Ghuman et al. 2005). These reports present associations that differ by type of human capital, but do not attempt to estimate causal effects that control for the behavioral determination of parental human capital in the presence of intergenerationally-correlated unobservables.

The present study uses an unusually rich longitudinal data set collected over 35 years in Guatemala to implement four innovations that address and hopefully overcome the five abovementioned limitations. *First*, we consider the impacts of mothers' intellectual human capital *and* mothers' biological human capital on children's outcomes. *Second*, we use both schooling attainment and cognitive skills as measures of maternal intellectual human capital. *Third*, in our preferred estimates, we treat all measures of mothers' human capital as behaviorally determined, and we use instrumental variable (IV) estimates to control for random measurement errors in the indicators of mothers' human capital. *Fourth*, we consider indicators of children's intellectual human capital *and* children's biological human capital as outcomes. These innovations yield important changes in our empirical understanding of the impacts of mothers' human capital on children's human capital in the studied context. Our findings suggest that the impacts are larger than found using standard methodologies, and that they vary by type of mothers' or children's human capital.

In the following, we present the conceptual framework (Section 2), the data (Section 3), alternative estimates for each of the children's human capital outcomes considered (Section 4), and then conclude (Section 5).

2. CONCEPTUAL FRAMEWORK

The returns to investments in women's human capital, in terms of their children's human capital, may be realized through a number of pathways. *First*, mothers with more intellectual human capital may be more likely to seek health and childcare information, and may be more aware of and likely to adopt behaviors that result in better-educated and healthier children. These behaviors could be related to nutrition and the care of children, such as breastfeeding, proper diet, better hygiene, and illness management (Webb et al. 2008a, 2008b)], as well as behaviors that enhance their children's intellectual development and school performance. *Second*, better maternal nutritional status before and during pregnancy may lead through "biological" pathways to better nutrition in utero and higher birth weights for the women's children, resulting in healthier children over their life cycles. "Biological" human capital is also thought to operate through the development of cognitive potential in early childhood (e.g., Engle et al. 2007). *Third*, more maternal human capital may be associated with shifts from child quantity to child quality, in part because a higher level of maternal human capital raises the opportunity costs of the women's time. *Fourth*, women with better human capital may attract spouses with better human capital; this may have positive effects on their children's human capital in addition to effects coming directly through the mothers.[5]

As noted in the introduction, many studies in both developing and developed countries show positive associations between maternal human capital and children's human capital, in a manner consistent with the possible importance of the above-described pathways (Cleland and Van Ginneken 1988; Brooks-Gunn, Klebanov, and Duncan 1996; Thomas 1994; World Bank 2001). However, within a dynamic life-cycle framework, both the intellectual human capital (e.g., education, as measured by schooling attainment or adult reading comprehension and nonverbal skills) *and* biological human capital (e.g., long-run nutritional status, as measured by height) of mothers reflect behavioral choices that depend on observed and unobserved individual and family backgrounds, as well as other characteristics. Some individuals and families may have unobserved attributes that lead to greater investments in intellectual and biological human capital, such as abilities and motivations for education that are rewarded in labor markets, or better health-seeking behaviors and greater food availability. If the estimation methods utilized in a given study do not control for the behavioral determinants of maternal human capital, the determined associations with outcomes in the children's generation may be biased.

Our conceptual framework for investigating the five issues noted in the introduction considers the life cycle to have a series of stages. One of those stages is adolescence-young adulthood, during which time (for the society under consideration) most individuals initiate first unions, parenting, and child rearing. Women have a vector of human capital stock (K) that includes intellectual and biological human capital, and determines the results of their union formation in terms of spousal characteristics and children's human capital. To facilitate exposition, we denote grandparents as $G1$, mothers as $G2$, and children as $G3$.

Let Y be a vector of $G3$ human capital outcomes, such as health, nutrition, and schooling. The basic goal of this study is to estimate how Y depends on the intellectual and biological capital of $G2$ (K), measured for the ages at which women make decisions regarding first unions and parenting, in the society under study. We assume that these human capital assets are the only assets that adolescent women bring

[5] We do not attempt to identify the indirect effects of spouses' human capital from the other effects that women have on their children's human capital, to avoid including too many right-side behavioral variables in our specifications. Thus, we herein estimate the total effects of women's human capital on their children's human capital, whether such effects are direct or indirect (e.g., through the women's spouses' assets or other pathways).

to spouse/partner acquisition, childbearing, and child rearing.[6] We posit that there is a linear approximation for what determines *Y*, given *G*2 human capital stocks (*K*), predetermined observed individual *G*3 characteristics (*I*) (such as the gender of the child and whether he/she is a twin), unobserved inherited *G*3 endowments (E_0) that are correlated across generations (such as innate ability and health), and a vector of stochastic disturbance terms (*V*), with one element for each different outcome, as follows:

$$Y = a_0 + a_1 K + a_2 I + a_3 E_0 + V, \tag{1}$$

where a_i represents the matrices of the coefficients to be estimated.

We seek to obtain good (consistent) estimates of the coefficients of maternal intellectual and biological human capital in relation (1); these are the components of *K* associated with each component in *Y*. However, estimation of relation (1) is a challenge because the *G*2 human capital that results, for example, in better *G*3 biological or intellectual capital often reflects prior behavioral choices. As a result, OLS or similar estimates of relation (1) are likely to be inconsistent, particularly if there are intergenerationally-correlated endowments, such as genetic tendencies.

To deal with these possible estimation problems, we first assume that mothers (*G*2s) and their parental families (*G*1s) make investments in prior life-cycle stages that determine the components of *K*. These investments are made within a dynamic, reduced-form demand context, given (1) the initial conditions, which include *G*1 family background (F_0), initial community prices and policies (C_0), genetic and other endowments (E_0), and individual *G*2 characteristics (I_0) such as birth date; (2) the changes that occurred from the time of the births of the *G*2s until they were of age to initiate partnerships and have children, such as changes in social service provision, markets, and policies (ΔC), all of which are conditional on each *G*2's birth date and subsequent age; and (3) unobserved idiosyncratic influences (*W*) on the *G*2s' human capital stock (e.g., random disease shocks). It then follows that

$$K = K(F_0, C_0, E_0, I_0, \Delta C, W). \tag{2}$$

This expression encapsulates the results of many decisions that the *G*1s, and then increasingly the *G*2s, make over the adolescent/young adult periods of the *G*2s, given initial conditions and time-varying factors outside family control. The elements in relation (2) are generally vectors of individual and community opportunities, and the constraints to which families respond. One example is genetic endowments (E_0), a vector that includes innate "ability" endowments related to learning, and "physical" endowments related to physical growth.[7]

Consideration of relations (1) and (2) illustrates two of the important limitations of the prior estimates made using relation (1), as described in the introduction. First, the biological and intellectual human capital of the *G*2s are determined in part by genetic and other endowments (E_0) that are also posited to affect the outcomes of interest in relation (1), either directly or through intergenerational correlations between the endowments of *G*2s and *G*3s. To obtain consistent estimates of the impacts of the intellectual and biological capital of the *G*2s on the *G*3s' outcomes of interest, some combination of data and estimation method must be used to avoid biases that would otherwise result from correlations

[6] In the utilized data, almost a third of males brought household and productive assets to their unions, whereas only 13.8 and 1.3 percent of women brought household and productive assets, respectively, to their unions (Quisumbing et al. 2005). Thus, women mostly brought their human capital assets into unions and childbearing. Moreover, only very low correlations are seen between mothers' human capital and the physical assets they brought into unions; therefore, excluding the latter from our specifications does not create substantial omitted variable biases in the coefficient estimates of interest.

[7] These various endowments may be significantly—but not necessarily positively—correlated. A recent study in the United States, for example, finds that endowments related to schooling and earnings are negatively related to physical health (Behrman and Rosenzweig 2004). Estimates of adult cognitive skill production functions for the data utilized in the present study are consistent with such a possibility (Behrman et al. 2008). If this is the case, our failure to control for genetic endowments could result, for example, in overestimation of the effect of maternal intellectual human capital on child schooling, but underestimation of the effect of maternal biological human capital on child schooling.

between the $G2$s' biological and intellectual capital and the expanded compound error term in relation (1), which includes unobserved genetic and other endowments (E_0) in addition to the idiosyncratic error (V). This problem can be addressed in principle by directly controlling for genetic and other endowments (E_0), using either random assignment of $G2$ human capital (K), or instrumental variable (IV) methods in which the components of $G2$ human capital (K) in relation (1) are replaced by their predicted values from relation (2), as the latter are not correlated with the unobserved E_0 and are therefore not correlated with the compound disturbance in relation (1). In the present (and almost all prior) data sets, only the latter option is viable.[8] It is notable that IV estimates also control for random measurement error, which tends to bias estimated coefficients toward zero. Because the effects of omitted variable bias due to endowments may oppose the effects of random measurement error, the IV estimates may be greater or smaller than the OLS estimates, depending on which of these potentially opposing biases is larger. In this way, IV estimates deal with both the third and fourth issues raised in the introduction; however, the impact on the estimated coefficients may depend on which issue is more important if they are opposing in their effects, as emphasized in studies focusing on omission of the so-called "ability" bias.[9] Second, the components of K are all determined at least in part by the same initial conditions (F_0, C_0, E_0, I_0), along with some common observed community changes (ΔC) and unobserved influences (W). As a consequence, the $G2$s' intellectual capital and biological capital are likely to be correlated, and estimates that fail to control for both components of K (as seen in most of the existing literature) are likely to suffer from omitted variable bias.[10] In other words, if both maternal intellectual and biological human capital should be included on the right-hand side of relation (1), but only one is actually included (e.g., maternal intellectual human capital as represented, for example, by schooling), then the coefficient estimate for that component of human capital is likely to be biased due to exclusion of the other (correlated) component of human capital.

[8] Within-$G2$ sibling estimates could be used to control for average family genetic endowments, as described in Behrman and Wolfe (1987a, 1987b), but subsequent studies suggest that individual-specific deviations from family averages have important impacts on human capital investments (Behrman, Rosenzweig, and Taubman 1994, 1996).

[9] As noted in Behrman and Rosenzweig (1999), within much of the economics literature the term "ability bias" likely refers to any unobserved endowment, including innate ability and unobserved dimensions of families and childhood neighborhoods shared by siblings (or by twins in particular). Therefore, we put "ability" in quotation marks here.

[10] We note that $G1$ human capital may be correlated with the unobserved endowment, E_0. Below, we use Hansen J statistics to test whether $G1$ characteristics are legitimate instruments for $G2$ human capital in relation (1).

3. DATA

The relations posited in Section 2 to explore the five issues raised in the introduction have demanding data requirements. To meet these requirements, we use an unusually rich, longitudinal data set collected over a 35-year period. The data include alternative measures of *G*2 intellectual and biological human capital, *G*3 intellectual and biological human capital, *G*1 family background, and exogenous "shocks" or "innovations" from an experimental nutrition intervention as well as market and policy changes.

3.1. General Description of the Data

In the early and mid-1960s, protein deficiency was seen as the most important nutritional problem facing the poor in developing countries, and there was considerable interest in the possibility that this deficiency affected children's ability to learn. The Institute of Nutrition for Central America and Panama (INCAP), based in Guatemala, became the locus of a series of preliminary studies on this subject in the latter half of the 1960s (see Habicht and Martorell 1992; Martorell, Habicht, and Rivera 1995; and, especially, Read and Habicht 1992). These preliminary studies informed the development of a larger-scale supplementation trial that began in 1969.

The data used in this study are based on that larger INCAP supplementation trial, collected during 1969-77 for all children zero to seven years old and all pregnant and lactating women in four rural Guatemalan villages.[11,12] The females who were zero to seven years old in 1969-77 (and 26-42 years old in 2002-4) are our *G*2 mothers (often referred to simply as "*G*2s"); their parents are our *G*1s; and their children are our *G*3s. Cohorts of newborns were included until September 1977. Data collection for individual *G*2s ceased when they reached seven years of age. The birth years of *G*2s included in the 1969-77 longitudinal data collection thus ranged from 1962 to 1977, and their ages ranged from 0 to 15 years when the intervention ended. Therefore, the length and timing of exposure to the nutritional interventions (described below) for a particular *G*2 depended on her birth date. For example, only children born after January 1969 and before October 1974 were exposed to the nutritional intervention throughout 0 to 36 months of age, which the nutritional literature posits as a critical time period for children's growth (see Maluccio et al. 2009; Martorell, Habicht, and Rivera 1995; Martorell et al. 2005; and the references therein). Recent estimates also suggest that this period is critical for the impact of early-life nutrition on completed schooling, adult cognitive skills, and wage rates (Hoddinott et al. 2008; Maluccio et al. 2009; Victora et al. 2008).

Two villages, Conacaste and San Juan, were randomly assigned to receive a high protein-energy drink, *Atole*, as a dietary supplement. *Atole* contained Incaparina (a vegetable protein mixture developed by INCAP), dry skim milk and sugar, and had 163 kilocalories (kcal) and 11.5 g of protein per 180-ml cup. This design reflected the prevailing view of the 1960s that protein was the critically-limiting nutrient in most developing countries. This *Atole* (which is the Guatemalan name for hot maize gruel) was pale gray-green and slightly gritty, but had a sweet taste.

In designing the data collection, there was considerable concern that the social stimulation associated with attending feeding centers (e.g., observation of children's nutritional status and the monitoring of *Atole* intake) might affect children's nutritional outcomes, thus confounding efforts to understand the impact of the supplement per se. To address this concern, an alternative drink, *Fresco*, was

[11] Three hundred villages were screened to identify those of appropriate size, compactness (so as to facilitate access to feeding stations, health centers, and psychological testing sites, see below), ethnicity, diet, schooling levels, demographic characteristics, nutritional status, and degree of physical isolation. From this screening, two pairs of similar villages were selected: Conacaste and Santo Domingo (relatively populous villages) and San Juan and Espíritu Santo (relatively less populous villages).

[12] This population has been studied intensively, with particular emphasis on the impacts of the nutritional intervention (Martorell et al. 2005 provide references to many of these studies).

provided in the villages of Santo Domingo and Espíritu Santo. *Fresco* was a cool, clear-colored, fruit-flavored drink. It contained no protein and only sufficient sugar and flavoring agents for palatability. It contained fewer calories per cup (59 kcal/180 ml) than *Atole*. Several micronutrients were added to the *Atole* and *Fresco* in amounts that achieved equal concentrations per unit volume. This addition was made to sharpen the protein contrast between the drinks; the energy content differed, of course, but this was not recognized to be of central importance at the time.

The nutritional supplements (i.e., *Atole* or *Fresco*) were distributed through supplementation centers and were available daily, on a voluntary basis, to all members of the community during times that were convenient to mothers and children, and did not interfere with usual meal times.[13] Since we are herein using the differential "intent to treat" exposure to these nutritional supplements during critical early-life periods as first-stage instruments to aid in the estimation of relation (2), a critical question is to what extent the intervention design resulted in differences in access to calories, proteins, and other nutrients. In addressing this question, we can exploit the intensive nature of the survey and observational work associated with the intervention. Averaging over all *G*2s in the *Atole* villages (e.g., both those who consumed any supplement and those who never consumed any), children 0-12 months were supplemented by approximately 40-60 kcal per day, children 12-24 months by ~60-100 kcal daily, and children 24-36 months by ~100-120 kcal per day (Schroeder, Kaplowitz, and Martorell 1992, Figure 4). Children in the *Fresco* villages, in contrast, consumed virtually no *Fresco* between the ages of 0-24 months (averaging at most 20 kcal per day) with this figure rising to approximately 30 kcal daily by age 36 months (Schroeder, Kaplowitz, and Martorell 1992; Islam and Hoddinott 2009). The micronutrient intakes from the supplements were therefore larger for *Atole* villages than *Fresco* villages.

Multidisciplinary research teams conducted several follow-up rounds of data collection on *G*2s and their children (*G*3s). The first one, conducted in 1987-88, targeted the *G*2s who were 11 to 26 years of age in 1988. It was feasible to include those who remained in the original villages, as well as migrants who moved to Guatemala City or the provincial capital of the study area. This data collection focused on the impacts of nutritional improvements during the critical period of gestation and the first three years of subsequent human capital formation, as measured by body size, working capacity, maturation, intellectual functioning, and school achievement, as well as family formation and occupation (Martorell, Habicht, and Rivera 1995). Of the 2,392 individuals 0-15 years old in the original 1969-77 data collection, 224 had died by 1987. Of the 2,168 surviving *G*2s, 1,574 participated in the 1987-88 data collection, for a coverage rate of approximately 73 percent. The rate of coverage was slightly higher for women (76 percent) than for men (69 percent) (Rivera, Martorell, and Castro 1993).

Between 1991 and 1996, investigators conducted a surveillance of births (*G*3 offspring of the original *G*2 sample members) in the original villages (out-migrants were not studied). In 1996, the data collection was expanded to include a surveillance of pregnancies and to carry out longitudinal data collection on the *G*3 offspring. Between 1996 and 1999, information was collected on all *G*3s born during 1996-1999, as well as *G*3s who were born before 1996 and were less than three years of age at the time of study onset in 1996. All of these *G*3s were followed to the age of three years or the study closeout, whichever came first. The data obtained included birth weight and length, weight and length at periodic intervals, morbidity and health-seeking behavior, breastfeeding, consumption of complementary foods, *G*2s' functional competence and intellectual functioning, and mother-child interactions (Ramakrishnan et al. 1999). Between 1991 and 1999, 698 *G*3s arising from 392 *G*2s were measured at birth. In 1996-1999, 570 *G*3s from 363 *G*2s were routinely followed for anthropometric measurements through the age of three years.

Finally, a multidisciplinary team of investigators, including the authors of this paper, undertook follow-up data collection in 2002-4 on all *G*2s from the 1969-77 data collection. In 2002-4, these individuals ranged from 25 to 42 years of age. Figure 1 shows the distribution of the 1,162 *G*2 women 0-

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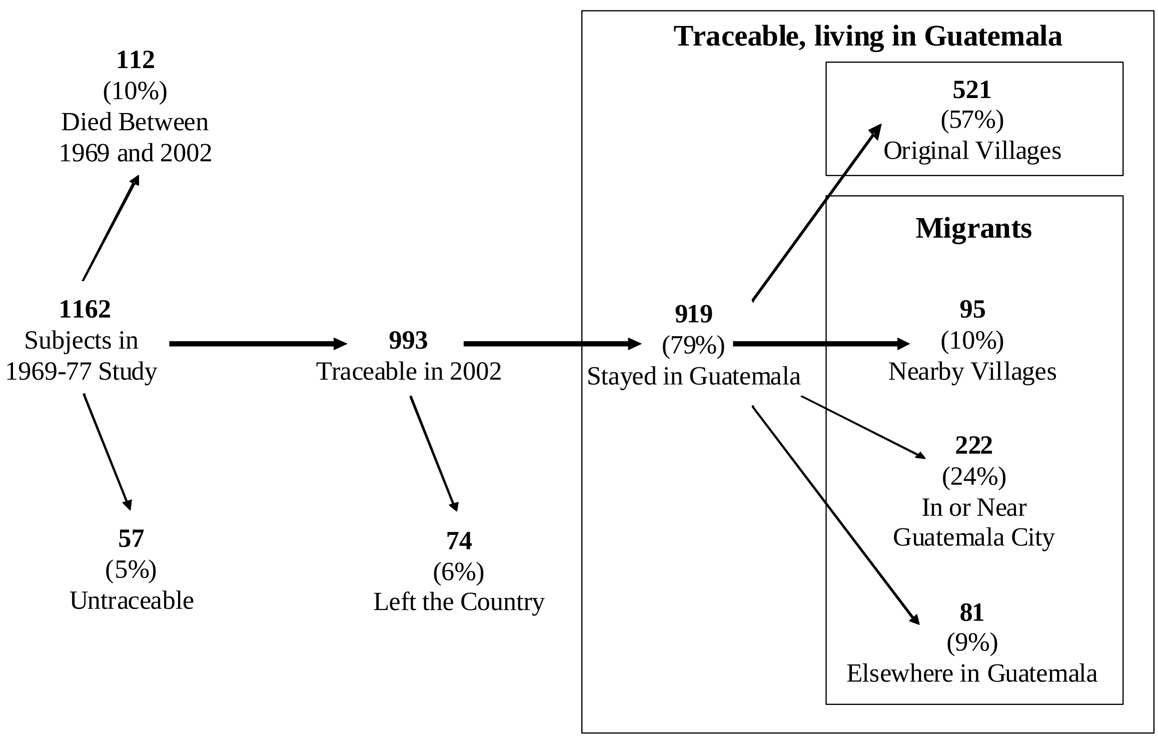
[13] A program of free primary medical care was provided throughout the period of data collection. Periodic preventive health services, such as immunization and deworming campaigns, were conducted in all four villages.

15 years old in the original 1969-77 sample at the time of the 2002-4 data collection: 919 (79 percent) were alive and known to be living in Guatemala, while 10 percent had died, 6 percent had migrated abroad, and 5 percent were not traceable. Of the 919 *G*2 women available for data collection, 521 lived in their original villages, 95 lived in nearby villages, 222 lived in or near Guatemala City, and 81 lived elsewhere in Guatemala. Of the total sample of 919 *G*2 women, 649 (71 percent) finished the complete battery of applicable interviews and measurements, and 818 (89 percent) completed at least one interview during the 2002-4 data collection (Grajeda et al. 2005).

Figure 1. Sample sizes for residents and migrants: Women only



A census of the four villages was conducted during each major data collection (i.e., in 1967, 1975, 1987, 1996, and 2002). These censuses contain valuable information on the family backgrounds of the *G*2s, including their *G*1 parents' ages, schooling attainments, and asset-holdings. The censuses in more recent years are additional sources of information about the *G*3 children, including attendance and completed grades of schooling. Using the 1996 and 2002 censuses, we are able to identify 1,318 *G*3s over age seven years whose 558 *G*2 mothers were participants in the original data collection.

We draw upon information on all three generations (*G*1, *G*2, *G*3) for our analyses. Although this enriches our analysis, it also increases the chance of missing data, including that arising through attrition. Of the 919 potential female *G*2s available in 2002-4, 628 (68 percent) had at least one live birth, as well as all the data necessary to be included in our analyses. The necessary data included information on schooling and fertility (from the 2002-4 data collection), data on cognitive functioning during late adolescence and late adolescent height (representing long-run nutritional status, our key indicator of *G*2 biological human capital) from information collected during either the 1988 or 2002-4 data collections, depending on age. As might be expected, these criteria for inclusion of *G*2s and *G*3s into our analysis reduced our sample size.

For example, in our analysis of the impact of maternal schooling and height on *G*3 birth weight, the *G*2s had to fulfill the following criteria: completed fertility and schooling questionnaires from the 2002-4 study; height measurements and scores of cognitive and noncognitive abilities from either the

2002-4 or 1987-8 studies; and at least one live birth between 1991 and 1999 while the *G*2 was living in one of the four villages. These requirements reduced the analysis sample to 576 *G*3 children arising from 327 *G*2 mothers (36 percent of the 919 potential *G*2 female subjects in 2002-4 and 52 percent of the 628 women who had all necessary data and at least one live birth). Likewise, our analyses of the determinants of *G*3 nutritional status at 36 months include 296 mothers and 459 of their children, and our analyses of *G*3 schooling include 484 mothers and 1,175 of their children.

The high rates of attrition (in the broad sense of the necessary exclusion of individuals lacking all data needed for a given analysis) not only reduce our sample sizes, but may also be nonrandom. This is especially relevant when we consider that the mothers included in our analyses were generally nonmigrant, in that they were present in the four communities during the intervention and in the 1990s, and were accessible (although not necessarily in the communities) in 2002-4. Appendix Tables B.1-B.3 present probit regressions on the probability of a *G*3 being in the estimation samples for *G*3 schooling, birth outcomes, and anthropometry at three years old. Similar to other studies using these data (e.g., Behrman et al. 2008; Hoddinott et al. 2008; Maluccio et al. 2009), we compute attrition weights using methods parallel to those in Fitzgerald, Gottschak, and Moffitt (1998), and use them in subsequent analyses. All regression results presented herein thus include corrections for attrition. Similar to Behrman et al. (2008), Hoddinott et al. 2008, and Maluccio et al. (2009), we do not find large impacts of attrition on the estimated coefficients. (The estimates from analyses that do not correct for attrition can be made available upon request.) Finally, a number of these *G*3s are siblings or half-siblings, so we control for mother-cluster effects in the estimation of the standard errors that are reported in Tables 3 and 4 (and Appendix Tables B.4-B.6).

3.2. Central Variables for the Analysis

Table 1 presents the means and standard deviations (SD) for the *G*3 human capital outcome variables, as well as the percentage of the variance in outcomes that is due to village effects. The latter are of interest because the more village effects dominate individual or household-level effects, the less likely we are to demonstrate individual effects of maternal human capital on children's human capital. Village effects account for a very small proportion of the variance across the different outcomes (ranging from 0.1 percent for schooling attainment to 3.7 percent for length-for-age); this suggests that most of the variance in children's outcomes is due to individual and household variability. To obtain the greatest precision in our estimates, we use all available observations for each estimate, although these vary across outcomes due to different data sources and missing information on particular variables of interest. Table 2 presents the means and SDs for the explanatory variables and instruments. Below, we briefly define the dependent variables (*G*3 outcomes), right-hand-side endogenous variables, right-side *G*3 observed individual characteristics, initial conditions, and observed shocks that help identify IV estimates.

Table 1. Summary of *G*3 human capital outcomes

	Mean	SD	% Variance due to village effects	N	Clusters[a]
Child intellectual human capital					
Schooling attainment[b]	0.02	2.64	0.1	1,175	484
Child biological human capital					
Anthropometry at birth					
Birth weight (kg)	2.98	0.46	1.5	576	327
Birth length (cm)	48.24	2.13	0.5	556	320
36-Month anthropometric Z-scores					
Length-for-age (LAZ)	-1.79	1.02	3.7	459	296
Weight-for-age (WAZ)	-1.26	1.09	1.8	459	296
Weight-for-length (WLZ)	-0.26	0.96	2.0	459	296

Notes:
[a] The number of clusters indicates the number of mothers of *G*3 subjects.
[b] Difference in schooling grades completed from age-cohort mean (positive if grades schooled > cohort mean).

Table 2. Summary of explanatory variables and instruments, by G3 human capital outcomes[a]

Explanatory variables	*G*3 schooling attainment sample		*G*3 anthropometry at birth[b] sample		*G*3 36-month anthropometric Z-scores sample	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
*G*2 Intellectual capital						
Grades of schooling	3.7	2.9	3.6	2.8	3.6	2.8
Cognitive skills[c] (percentiles, %)	50.2	26.5	53.7	25.4	51.4	23.3
*G*2 Biological human capital						
Height (cm) at age 18	150.3	5.6	150.3	5.3	150.0	5.3
Other controls						
*G*3 gender (1=male)	0.51	0.50	0.50	0.50	0.52	0.50
*G*3 twin	0.01	0.11	0.01	0.12	0.01	0.10
Instruments						
***G*2 community characteristics and shocks**						
*G*2 Lived in communities when 0-36 months of age	0.35	0.48	0.35	0.48	0.37	0.48
*G*2 exposed to *Atole* when 0-36 months of age	0.21	0.41	0.21	0.41	0.21	0.41
*G*2 born in San Juan	0.24	0.42	0.17	0.38	0.18	0.38
*G*2 born in Conacaste	0.33	0.47	0.36	0.48	0.33	0.47
*G*2 born in Espíritu Santo	0.17	0.38	0.19	0.39	0.21	0.41
Student-teacher ratio in community when G2 was age 7	41.6	10.1	40.8	10.3	40.5	10.4
Number of grades available in community when *G*2 was age 7	5.7	0.6	5.8	0.6	5.8	0.5
Good local job market when G2 was age 15	0.68	0.47	0.69	0.46	0.68	0.47
***G*2 family and individual characteristics**						
*G*1 mothers' schooling	1.1	1.5	1.1	1.5	1.2	1.5
*G*1 fathers' schooling[d]			1.6	2.0	1.6	2.0
*G*1 household wealth index in 1975	-2.84	0.90	-2.90	0.89	-2.91	0.86
Missing *G*1 mothers' schooling	0.01	0.12	0.01	0.08	0.01	0.08
Missing *G*1 fathers' schooling			0.03	0.16	0.03	0.16
Missing *G*1 household wealth index in 1975	0.15	0.36	0.06	0.25	0.08	0.27
Death of *G*1 mother or father before G2 reached age 15	0.06	0.25	0.07	0.26	0.07	0.26
Birth year	1,968.4	4.0	1,969.7	4.3	1,970.2	4.2
*G*2 is a twin	0.02	0.13	0.02	0.13	0.03	0.16

Notes:

[a] These summary statistics are at the level of *G*2 mother (except for *G*3 gender and twin). Table 1 gives the sample sizes (e.g., n = 1,175 for *G*3 children and 484 for *G*2 mothers for *G*3 schooling, n = 576 (556) for *G*3 children and 327 (320) for *G*2 mothers for anthropometry at birth, and n = 459 for *G*3 children and 296 for *G*2 mothers for *G*3 36-month anthropometric Z-scores).

[b] Summary statistics for anthropometry at birth are based on mothers in birth weight regression. Birth length sample is slightly smaller (see note a).

[c] Cognitive skills are weighted percentiles for reading-comprehension scores and nonverbal scores, with weights for *G*3 schooling estimates of 0.90 and 0.10; for birth weight estimates of 0.10 and 0.90; for birth length estimates of 0.30 and 0.70; for 36-month LAZ estimates of 0.30 and 0.70; for 36-month WAZ estimates of 0.80 and 0.20; for 36-month WLZ estimates of 1.00 and 0.00 (see Appendix A). For anthropometry at birth, the mean and SD in the table is for birth weight (those for birth length are 52.2 [22.9]). For 36-month anthropometric Z scores, the mean (SD) in the table is for LAZ (those for WAZ are 48.4 [24.4] and those for WLZ are 47.2 [27.4]).

[d] Overidentification tests suggest that *G*1 fathers' schooling should not be included in instruments set for *G*3 schooling.

Dependent Variables: G3 Outcomes (Y)

G3 Intellectual Human Capital (*Y*)

Schooling of children by 2002-4: difference in the grade of schooling completed by each child from the age-cohort mean, for all *G*3s over age seven years, taken from the 1996 and 2002-4 censuses. Given the construction, the means are not significantly different from zero. However, the SD of 2.6 indicates substantial variation.[14]

G3 Biological Human Capital (*Y*)

Anthropometry at birth: birth weight in kilograms and length in centimeters, collected during 1991-99. The mean birth weight of *G*3s in this study is 3.0 kg, which is above the standard cutoff of 2.5 kg for low birth weight. However, birth weight varies considerably, and 13 percent of the birth weights are below 2.5 kg. The mean birth length is 48.2 cm, with a standard deviation of 2.1 cm.

Nutritional status at 36-months: length-for-age (LAZ), weight-for-age (WAZ), and weight-for-length (WLZ) Z-scores from the 1996-1999 data collection.[15] These scores indicate that the study population is (not surprisingly) malnourished relative to the reference population. This is particularly evident with regard to stunting (LAZ < 2.0 SD below the reference median), which is generally considered an indicator of the long-run impact of early childhood nutrition[16] on subsequent development (e.g., Victora et al. 2008). Indeed, 43 percent of the children have LAZ values below -2.0.

Right-Hand-Side Endogenous Variables

G2 Intellectual Capital at or Before First Parenting (*K*)

In addition to mothers' schooling attainment, which is the standard measure used in the literature, we use maternal cognitive skills as an alternative measure. We argue that this measure better represents mothers' knowledge, because it is affected by endowments and experiences before and after schooling, in addition to schooling itself (see Behrman et al. 2008).

*G*2 Schooling Attainment: completed grades of schooling, as measured in 2002-4. The average grade completed for women included in our analyses is about 3.7 (SD 2.8) for the subsamples divided by different child outcomes. Schooling attainment, thus, was low for the *G*2s considered herein.

*G*2 Cognitive Skills: weighted average of percentile scores on the vocabulary and reading-comprehension modules of the Inter-American Reading and Comprehension Tests (IARC, see Manuel 1967) and of nonverbal skills (Raven's Progressive Matrices; see Raven, Court, and Raven 1984),[17] which are taken from test results obtained in 1988-9 and 2002-4 and represent maternal cognitive skills at or before first parenting. The weights are determined using coefficients on maternal IARC and Raven's scores from IV regressions in which both are included on the right side (along with maternal height) and

[14] We explored the possibility of including cognitive scores (Bayley's test scores) for children less than three years of age in the 1996-9 data collection. Perhaps because of limited precision resulting from the relatively small number of *G*3s for which this exploration was possible, the coefficient estimates for the *G*2 human capital components, while positive, were not statistically significant. We therefore do not include this *G*3 outcome measure in the present analysis.

[15] Z-scores give the number of standard deviations from the median of the distribution for a reference population (we use the NCHS-CDC standards; see http://www.cdc.gov/GROWTHCHARTS/). Not all *G*3s were measured at exactly 36 months. Z-scores were regressed on dummy variables for age at time of measurement for all children to obtain age-paths for the Z-scores. For children who were not measured exactly at 36 months, these estimates were used to interpolate to 36 months from the measurement nearest to 36 months.

[16] Nutritional status, in turn, is thought to reflect the combined impacts of nutrients consumed, disease history, and stimulation.

[17] Raven's Progressive Matrices are a common nonverbal measure of interpretative cognitive skills, whereby the respondent is given a set of shapes and patterns and asked to supply the missing piece.

treated as behaviorally-determined. The weights imply that *G*2 reading-comprehension scores are the dominant indicator of mothers' cognitive skills for *G*3 schooling attainment (with a weight of 0.90) and for the Z-scores for weight-for-age at 36 months (0.80 for WAZ, 1.00 for WLZ). On the other hand, *G*2 nonverbal skills are the dominant indicator of mothers' cognitive skills for *G*3 anthropometry at birth (0.90 for birth weight, 0.70 for birth length) and for *G*3 Z-scores for length-for-age at 36 months (0.70 for LAZ). (Appendix A gives more details about the construction of this variable.)

*G*2 Biological Capital Stocks at or before First Parenting (*K*)

*G*2 Long-Run Nutritional Status: height (cm) at age 18, which is the age by which most females have attained their adult height.[18] The mean height is about 150 cm (SD 5.3), reflecting that this population is fairly short, apparently resulting from poor nutrition, particularly in early life (Schroeder et al. 1995).

Right-Side G3 Observed Individual Characteristics (I)

Gender: male = 1.

Twin: whether the *G*3 is a twin, which may have long-run implications associated with the generally lower birth weight of twins, as well as their higher probability of prematurity (e.g., Behrman and Rosenzweig 2004). For this population, twins are generally natural rather than the result of assisted reproductive technologies, as is relatively frequent in higher-income populations.

Initial Conditions (F_0, C_0, I_0) That Help Identify IV Estimates

*G*1 characteristics and family background (F_0): *G*1 schooling attainments, as well as a constructed socioeconomic status score that is the first principal component of both the assets owned and the housing characteristics of the *G*1 households in 1975 (Maluccio, Murphy, and Yount 2005), and a dummy variable for whether either *G*1 parent died before *G*2 was age 15 years.

Fixed community characteristics during *G*2's childhood (C_0): village-fixed effects to control for permanent community differences in learning and health/nutrition environments, in part because of different experiences of prior generations regarding schooling and occupational structure (Bergeron 1992; Maluccio et al. 2005).

Fixed individual *G*2 characteristics (I_0): birth year and whether *G*2 is a twin.

Observed Shocks and Events (ΔC) That Identify IV Estimates

Natural, market or policy events (ΔC): community-level time-varying variables that relate as closely as possible to the timing of key decisions in *G*2s' human capital development.[19] For example, using information reported in earlier studies on infrastructure, markets, and services in the four villages (Pivaral 1972; Bergeron 1992), along with data from a retrospective study performed in 2002 (Estudio 1360 2002), we construct variables such as the student-teacher ratios and number of grades available (proxies

[18] We use a combination of the 1988 and 2002-4 data to construct this variable, taking the 1988 measure for those who were older than 18 in 1988, and the 2002-4 measures for those who were aged 11-18 years in 1988. We also use the 2002-4 measure of height for those who were older than 18 in 1988 but who were not measured at that time. About a quarter (24 percent) of women had their first live birth before age 18. While it is possible that having a pregnancy before the age at which adult height is achieved could affect achieved height, in the absence of information on height at the age of first birth, we use height at about age 18 as our measure of achieved height.

[19] Recent surveys of education in developing countries include references to a number of studies that provide evidence on the importance of school infrastructure and school quality and some studies that provide evidence of the importance of labor markets (Behrman 2008; Glewwe and Kremer 2006; Orazem and King 2008). The health and nutritional literature has long stressed the importance of infectious diseases, which, in turn, reflect the community disease environment, water and sanitation systems, and the health-sector infrastructure, in addition to family factors (Martorell 1997; Strauss and Thomas 1998).

for school quality) in the *G*2s' villages when they were most likely to start their schooling (age seven years), as well as work in local markets when the G2s were most likely making the decision to continue schooling or join the work force (age 15 years). The variable reflecting work availability in local markets (good local job market when *G*2 was age 15) is equal to one if a "boom" was occurring in any local market, such as increased *yuquilla* production in San Juan, vegetable cooperatives in Conacaste, or intensive hiring of community members at a cement factory near Conacaste and Santo Domingo (for a detailed description of the local markets, see Maluccio et al. 2005). Thus, while reflecting community-level characteristics, these variables vary by single-year age cohorts within each village, as well as across villages. Because these measures more closely relate the availability and longevity of schools and markets to the periods in a woman's life when critical decisions are made (e.g., attending school, working in the labor market), the use of these age-specific community data is an improvement over the more typical approach of including indicators about such factors in a given year for a population of various ages.

Experimental nutritional shocks (ΔC): whether the *G*2 was in a birth cohort exposed to the nutritional interventions underlying the original data collection (see Section 3.1) when she was 0-36 months of age and, if so, whether she was in an *Atole* village. These two measures of intervention exposure, which are both included in the first-stage estimates, are based on the birth year of the *G*2, the dates of operation of the interventions, and where the *G*2 lived as a child. Thus, although the experiment was conducted at the village level, not the individual level, this measure includes substantial exogenous variation across individuals, in terms of whether they were exposed during the critical first three years of life.

4. RESULTS

To establish a benchmark for comparison, we begin with OLS estimates wherein mothers' human capital is represented by only their schooling attainment, as is common in many studies. We then report IV estimates that control for the endogeneity of and random measurement error in biological maternal capital (mothers' height) if it adds significantly to the explanatory power of the relation, and maternal intellectual capital (cognitive skills) if it is more consistent than maternal schooling attainment with regard to the variance in the children's outcome. We use the term "preferred estimates" to refer to the specification with the representation of maternal human capital that is most consistent with the variance in the dependent variable. In describing these estimates, we use "significant" to refer to significance at the standard 0.05 level, unless we explicitly indicate the 0.10 level. We use "effect sizes" as in the biomedical literature (e.g., Engle et al. 2007; Victora et al. 2008) to facilitate comparison across *G*2-*G*3 human capital indicator combinations of the estimated relative effectiveness (or associations) of alternative *G*2 human capital measures on *G*3 human capital.[20]

OLS Estimates with *G*2 Human Capital Represented Only by Mothers' Schooling Attainment (Table 3)

These estimates indicate that maternal schooling attainment has significant positive associations with children's intellectual human capital, as represented by children's schooling attainment relative to the mean for each child's age cohort. For each additional grade of schooling completed by *G*2s, *G*3s are estimated to achieve an additional 0.1 grade above the mean for their age cohort. *G*3s whose *G*2 mothers have completed schooling 1.0 SD above the mean are estimated to have schooling attainment 0.3 grades above the age-specific mean, which is an effect size of 0.12. The OLS estimates also indicate that maternal human capital significantly increases two indicators of children's biological human capital: LAZ at 36 months and WAZ at 36 months (with the latter at the 0.10 significance level). These point estimates suggest that a 1.0-SD increase in maternal schooling attainment increases LAZ by 0.17 SD and WAZ by 0.10 SD. The standard estimates, however, indicate that G2 human capital has no significant impact, even at the 0.10 level, on birth weight, birth length, or WLZ at 36 months.

Table 3. OLS "standard" estimates of the impact of G2 maternal human capital (as represented by maternal schooling attainment) on G3 child human capital outcomes[a]

	Coefficient	t	Effect size
G3 child intellectual human capital			
Schooling attainment[b]	0.109	3.45***	0.12
G3 child biological human capital			
Anthropometry at birth			
Birth weight (kg)	0.011	1.46	0.07
Birth length (cm)	0.046	1.24	0.06
36-month anthropometric Z-Scores			
Length-for-age (LAZ)	0.059	2.76***	0.17
Weight-for-age (WAZ)	0.039	1.87*	0.10
Weight-for-length (WLZ)	-0.003	-0.17	-0.01

Notes:
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.
[a] Details of full estimates are found in Panel 1 of Appendix Tables B.4-B.6. The effect size is the change in number of SDs in the dependent child human capital outcome estimated to occur due to a one-SD increase in maternal human capital.
[b] Difference in schooling grades completed from age-cohort mean (positive if grades schooled > cohort mean).

[20] The effect size is defined as the number of sample standard deviations in the *G*3 human capital variables that would be induced to change (or are associated with, in the OLS case) with a 1.0-SD change in the *G*2 human capital variable.

IV Estimates Including Both Maternal Intellectual and Biological Human Capital (Table 4)

These estimates[21] indicate that *G*2 maternal human capital has significant impacts on all of our indicators of the *G*3s' intellectual and biological human capital (although significant only at the 0.10 level for children's birth length). With the exception of the impact on LAZ at 36 months, the effect sizes for the *G*2 intellectual human capital in our IV estimates, which range from 0.17 to 0.27, are larger than those in the OLS estimates. The preferred indicator of *G*2 intellectual human capital is maternal schooling for children's schooling and LAZ (although not significant even at the 0.10 level in the latter case). However, maternal cognitive skills are preferred for the other four indicators of children's human capital. *G*2 biological human capital has significant effects on three *G*3 human capital outcomes, namely schooling attainment relative to cohort means, birth weight, and LAZ. The effect sizes of *G*2 biological human capital in these cases are 0.31 to 0.46, which are larger than the effect sizes of *G*2 intellectual human capital for each of these three *G*3 human capital outcomes. In short, compared with the OLS estimates, our IV estimates show that (1) maternal human capital has larger estimated coefficients; (2) maternal cognitive skills tend to be more predictive than maternal schooling attainment when examining children's biological human capital; and (3) maternal biological capital is significant and has larger effect sizes than maternal intellectual capital for half of the *G*3 outcomes.[22]

[21] Appendix Table B.7 presents the first-stage results for the endogenous right-hand-side variables, *G*2 schooling and height, for selected *G*3 outcomes (one outcome from each of Appendix Tables B.4-B.6; estimates for other *G*3 outcomes are available upon request). Appendix Table B.8 presents analogous first-stage results for endogenous *G*2 cognitive skills and height. The identifying instruments are indicated in Section 3 (*G*1 father's schooling and the dummy variable indicating missing data are left out of the regressions for *G*3 schooling, to avoid over-identification). In all of the IV regressions, the F-test of the instruments excluded from the second stage indicates that the instrument sets are jointly significant (to at least the 0.001 level) in predicting the endogenous right-hand-side regressors. The Cragg-Donald F-test for weak instruments in our IV estimates (Panels 3 and 4) exceeds the critical value (e.g., of 4.43 for two endogenous regressors and 18 excluded instruments, as in Panel 4). This implies a bias relative to OLS of less than 0.30 (Stock and Yogo 2002) in estimates for G3 schooling (Appendix Table B.4) and birth weight (Appendix Table B.5), although the bias relative to OLS may be greater for LAZ at 36 months (Appendix Table B.6). Despite a 0.30 bias relative to OLS, these IV estimates suggest different impacts of maternal human capital on children's human capital compared to the standard OLS estimates. Thus, although we would like our estimates to perform better on the weak instrument test, these Cragg-Donald test results support our concern about how well the standard estimates represent the true causal impact of maternal human capital on children's human capital. The p-values for the Hansen J statistic for overidentification in the IV estimates (Panels 3 and 4) do not reject the null hypothesis that the instruments are independent of the second-stage disturbance term at the usual 0.05 significance level. Thus, these diagnostics suggest that our IV estimates are fairly satisfactory and preferable to the OLS estimates.

[22] Note that the first-stage estimates presented in Appendix Tables B.7 and B.8 are estimates of relation (2) where *G*2 human capital is treated as endogenous. Although estimating relation (2) is not the main focus of the paper, it is noteworthy that in the first-stage regression, *G*1 family background emerges as a more significant determinant than community shocks when considering *G*2 human capital, particularly adult height. More variables characterizing community shocks or interventions are significant in the equation for *G*2 years of schooling, but not cognitive skills or adult height. This suggests that *G*1 family background may play a more important role in determining investments in *G*2s, even if community shocks and interventions (particularly nutritional supplementation) had significant effects on completed schooling. As indicated in the immediately preceding note, however, Hansen J statistics do not reject the null hypothesis that the family background instruments included in the first-stage estimates are independent of the second-stage disturbance term, despite possible intergenerational correlations in endowments, as noted above.

Table 4. Preferred IV estimates of the impact of *G*2 human capital on *G*3 human capital outcomes[a]

	*G*2 intellectual human capital				*G*2 biological human capital		
	Coefficient	**t**	**Effect size**	**Indicator**	**Coefficient**	**t**	**Effect size**
*G*3 intellectual human capital							
Schooling attainment[b]	0.152	2.3**	0.17	Schooling	0.151	2.61***	0.32
*G*3 biological human capital							
Anthropometry at birth							
Birth weight (kg)	0.004	2.35**	0.22	Cog skills	0.027	2.64***	0.31
Birth length (cm)	0.018	1.92*	0.19	Cog skills			
36-month anthropometric Z-scores							
Length-for-age (LAZ)	0.031	0.79	0.08	Schooling	0.088	3.21***	0.46
Weight-for-age (WAZ)	0.012	2.68***	0.27	Cog skills			
Weight-for-length (WLZ)	0.007	1.98**	0.20	Cog skills			

Notes:
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.
[a] Details of full estimates are given in Panel 4 of Appendix Tables B.4-B.6 except for birth length (shown in Panel 3 of Appendix Table B.5) and WAZ and WLZ (shown in Panel 3 of Appendix Table B.6). The effect sizes are the change in number of SDs in the dependent child human capital outcome estimated to occur due to a one-SD increase in the specific maternal human capital indicator.
[b] Difference in schooling grades completed from age-cohort mean (positive if grades schooled > cohort mean).

5. DISCUSSION AND CONCLUSIONS

Most previous estimates of the impacts of maternal human capital on children's human capital are OLS estimates for the effects of maternal schooling attainment on children's schooling or, less commonly, children's nutrition as measured by anthropometric indicators. In this paper, we use unusually rich longitudinal data collected over 35 years in rural Guatemala to explore five limitations of these "standard" estimates. In the following, we first summarize what is suggested by our estimates regarding these five limitations in the literature, and then we summarize the substantive implications of our estimates.

5.1. Ability to Deal with the Five Limitations Affecting Previous Literature

First, most of the previous literature considers only mothers' intellectual human capital. We consider the impact on children's outcomes of not only mothers' intellectual human capital, but also mothers' biological human capital (in the form of maternal height, a measure of long-run nutritional status). We find that mothers' biological capital is a significant factor in three of the IV estimates; indeed, these three indicators are probably the most-emphasized children's human capital development indicators among the six considered herein. In these three cases, the estimated effect sizes are larger for maternal biological human capital than for maternal intellectual capital (Table 5, Panel 4). Moreover, if maternal biological human capital is constrained to have zero coefficient estimates in these three cases, the upward bias in the estimated coefficient of maternal intellectual capital is substantial, from 18 percent to 66 percent (Table 5, Panel 1), because maternal intellectual capital is proxying in part for maternal biological capital, as discussed for the model presented in Section 2.

Second, most of the previous literature represents mothers' intellectual human capital only by schooling attainment. Here, we examine both schooling attainment and maternal cognitive skills as measures of maternal intellectual human capital. We find that maternal cognitive skills are more consistent with the sample variation in four of the five indicators of children's biological human capital examined herein; where maternal intellectual human capital is significant, schooling attainment relative to peers from the same birth cohort was the sole indicator more consistent with maternal schooling. We also find (with the sole exception of LAZ at 36 months, for which neither of our maternal intellectual human capital indicators is significant) that the estimated effects sizes are, if anything, larger for maternal cognitive skills than for maternal schooling attainment (Table 5, Panel 2).

Third and *fourth,* most of the previous literature considers mothers' human capital to be independent of unobserved variables, such as innate abilities and preferences, and to be observed without measurement error. Here, we treat all measures of mothers' human capital as behaviorally-determined and use IV methods to control for random measurement errors in the indicators of women's human capital. When these methods are employed, the estimated impacts of the indicators of women's human capital are systematically higher (from 15 percent to 86 percent) than those based on OLS methods (Table 5, Panel 3). This result is consistent with the importance of random measurement error and/or the presence of unobserved determinants that have a negative (positive) effect on children's development and are positively (negatively) correlated with the observed indicators of maternal human capital. This result also contrasts with the notion of upward bias due to omitted "ability" (or other endowments), which has been a primary focus of the literature, although some reports have emphasized the importance of downward bias due to random measurement error (e.g., Ashenfelter and Krueger 1994).

Table 5. Summary of the implications of the alternative estimates for the five issues raised in the introduction[a]

	Panel 1	Panel 2		Panel 3		Panel 4	
	Percent change in coefficient estimate of preferred *G*2 intellectual human capital when *G*2 biological human capital added to relation and found to be significant	**Effect sizes of maternal schooling attainment vs. maternal cognitive skills, preferred *G*2 human capital indicator in bold**		**Percent change in coefficient estimate of preferred *G*2 human capital indicator if IV estimation instead of OLS (relative to IV estimate)**		**Effect sizes of *G*2 intellectual human capital and biological human capital**	
Dependent variables		**Schooling attainment**	**Cognitive skills**	**Intellectual human capital**	**Biological human capital**	**Intellectual human capital**	**Biological human capita**
***G*3 intellectual human capital**							
Schooling attainment[b] (grades)	-18%	**0.17**	0.20	44%	71%	0.17	0.32
G3 biological human capital							
Anthropometry at birth							
Birth weight (kg)	-22%	0.06	**0.22**	46%	30%	0.22	0.31
Birth length (cm)		0.15	**0.19**	47%		0.19	
36-month anthropometric Z-scores							
Length-for-age (LAZ)	-66%	**0.08**	-0.11	32%	15%	0.08	0.46
Weight-for-age (WAZ)		0.23	**0.27**	42%		0.27	
Weight-for-length (WLZ)		0.15	**0.20**	86%		0.20	

Notes:

[a] Panel 1 in this table is based on Panels 3 and 4 in Appendix Tables B.4-B.6 when Panel 4 gives preferred estimates (the only three cases in which this information is relevant); Panel 2 in this table is based on Appendix Tables B.4-B.6 (Panel 3 for birth length, WAZ and WLZ, and otherwise Panel 4); Panel 3 in this table is based on Appendix Tables B.4-B.6 (Panel 3 vs. Panel 1 for birth length, WAZ and WLZ, and otherwise Panel 4 vs. Panel 2); Panel 4 in this table is based on Appendix Tables B.4-B.6 (Panel 3 for birth length, WAZ and WLZ, and otherwise Panel 4).

[b] *G*3 difference in schooling grades completed from age-cohort mean (positive if grades schooled > cohort mean).

Fifth, among our *G*3 outcomes, we consider indicators of both children's intellectual human capital and children's biological human capital in order to examine variation in the effects of different types of *G*2 human capital on *G*3 human capital development. The estimates suggest variation among the children's outcomes; only maternal intellectual human capital is significant for birth length, WAZ, and WLZ, only maternal biological human capital is significant for LAZ, and both maternal intellectual and biological human capital are significant for the two most emphasized indicators of children's human capital in the literature, namely schooling attainment and birth weight (Table 5, Panel 4). Due to such variation in the importance of different types of maternal human capital across the children's outcomes, generalizations made from the impacts on only one or two children's outcomes is likely to be misleading. However, our results do not reveal a pattern, suggesting that for the children's intellectual (biological) human capital outcomes, maternal intellectual (biological) human capital dominates.

There is, however, some pattern with regard to which of the two indicators of *G*2 intellectual human capital is most predictive of different *G*3 outcomes. Only for children's schooling attainment is maternal schooling attainment more predictive; in all of the other cases in which maternal intellectual human capital is significant, maternal cognitive skills are more predictive of the children's outcomes than is maternal schooling attainment. This finding suggests that for most children's outcomes, maternal cognitive skills may better capture maternal intellectual human capital, whereas maternal schooling attainment is more predictive for children's schooling, perhaps because it relates more directly to this specific investment in children. Better-schooled mothers, for example, may be more cognizant of school requirements, such as attendance and homework. Finally, there is some variance, as noted in Section 3.2, in the weights of reading comprehension versus nonverbal skills when examining the children's outcomes for which maternal cognitive skills appear to be the preferred representation of maternal intellectual human capital. For example, maternal reading comprehension dominates for the children's weight-related measures at 36 months (WAZ, WLZ), but nonverbal skills dominate for birth anthropometry and LAZ at 36 months. These findings are consistent with recent work on the same study population showing that maternal schooling and acquired cognitive skills are associated with better hygiene practices (Webb et al. 2008a) and better maternal care during episodes of diarrhea (Webb et al. 2008b).

Thus, it appears that the most relevant maternal human capital indicators vary across children's human capital outcomes.

Future research on maternal-children human capital links would benefit from the adoption of strategies aimed at dealing with the five noted limitations of the previous literature, thereby moving beyond the standard methodology for understanding these relationships. Our doing so has in an important way affected our understanding of impacts of mothers' human capital on children's human capital in the studied context.

5.2. Implications of the Estimates of the Impacts of Maternal Human Capital on Children's Human Capital

Our preferred IV estimates, which included multiple dimensions of maternal and child human capital, suggest that (1) maternal human capital is more important than suggested by the OLS estimates; (2) maternal cognitive skills tend to be more predictive of children's biological human capital than does maternal schooling attainment for many child outcomes; and (3) for some important child human capital indicators (e.g., children's schooling attainment, birth weight, and length-for-age [LAZ] at age 36 months), maternal biological capital is significant and has larger effect sizes than maternal intellectual capital. Thus, our results suggest that the intergenerational links between maternal and child's human capital are stronger and more multidimensional than typically thought on the basis of standard estimates. This conclusion implies that there will be a greater challenge in breaking the intergenerational transmission of poverty, malnutrition, and intellectual deprivations, not only because of the strength and multidimensionality of the estimated maternal-child human capital effects, but also because effective interventions to improve women's biological and intellectual human capital often begin in utero or in early childhood, and thus will require a longer period before the returns in the investment are realized (compared to the case if more schooling were the only channel).[23] Nevertheless, in comparison with estimates calculated using the approaches dominant in the previous literature, our results support a stronger argument for improving women's human capital in terms of impacts on the human capital of the next generation. In particular, our estimated effects are 15 percent to 86 percent larger in our preferred IV estimates compared to our OLS estimates. It is important to note, however, that such support should recognize that women's human capital has both biological and intellectual components, and that the intellectual components reflect not just school attendance, but also the quality of schooling and the nature of pre- and post-schooling experiences.

[23] Although some assume that schooling is the only determinant of cognitive skills, estimates of cognitive skill production functions for this same sample with preschool-age and post-school-age experiences included along with schooling, and with all these experience treated as endogenous, find that both pre- and post-school-age experiences are quite important relative to schooling (Behrman et al. 2008).

APPENDIX A: CONSTRUCTION OF VARIABLES REFLECTING *G*2 MOTHERS' COGNITIVE SKILLS BEFORE OR AT FIRST BIRTH

In this study, the term "mothers' cognitive skills" reflects both reading comprehension and nonverbal test scores for ages prior to or at first birth, with the weights for these two components selected to maximize consistency with each of the children's outcomes in the preferred IV estimates.[24]

Maternal Nonverbal Cognitive Skills

In 1988-9 and 2002-4, all respondents were administered Raven's Progressive Matrices (Raven, Court, and Raven 1984), a widely-used nonverbal measure of interpretative cognitive skills, wherein the respondent is shown a set of shapes and patterns and asked to supply the "missing piece." At both time points, we administered the first three (and less advanced) of the five scales (A, B, and C with 12 questions each for a maximum possible score of 36), because pilot data suggested and subsequent survey data confirmed that few respondents were able to progress beyond the third scale. The estimated scores vary considerably within each cross-section, and nonverbal cognitive skills appeared to improve, on average, over time between the two cross-sections. Women scored a mean of 10.3 points in 1988-9, with a SD of 4.2 ($n = 683$), while women who took the test in 2002-4 scored a mean of 16.3 points with a SD of 5.4 points ($n = 779$). The 2002-4 mean score is significantly higher than the 1988 mean score ($p < 0.001$). When looking at the 551 women who took the test in both years, the average (SD) in 1988 was 10.2 (4.0) and the average (SD) in 2002 was 16.8 (5.5). In the 1988-9 data (Pollitt et al. 1993), the Raven's test exhibited adequate test-retest reliability (correlation of 0.87) and internal consistency for this population. The correlation between the tests conducted in 1988-9 and 2002-4 in our sample of 551 women who took both tests is 0.55 ($p < 0.001$).

Because many of our sample members were still of schooling age during the 1988-9 data collection (ages 11-25), and because the 2002-4 data collection took place well after initial child-bearing for many sample members (ages 25-42), we devised a composite measure of these two tests to approximate an "adult" Raven's score closest to the age at which the subject started to have children.[25] First, we predict the 1988 Raven's score (using the 2002-4 Raven's score, age in 1988, and gender; with age and gender both interacted with the 2002-4 score) for the 228 female subjects for whom we have a 2002-4 score but not a 1988-9 score. For subjects who were older than 18 years at the time of the 1988-9 Raven's test, we use their actual Raven's score from 1988-9 (or the predicted score, for those not present in 1988-9). For sample members who were 18 years old or younger at the time of the 1988-9 Raven's test, we correct their actual (or predicted) 1988-9 Raven's score to what we predict their score would have been had the individual been over 18 at the time. The utilized correction is the sum of the coefficients on age and age interacted with the 2002-4 score from the prediction regression described above, multiplied by the number of years away from "adulthood" (age 19) they were in 1988.

The mean "adult" Raven's score for women is 9.8 ($SD = 4.0$, $n = 911$). The correlations between this "adult" score and the 1988-9 and 2002-4 tests are 0.98 ($p = 0.000$) and 0.56 ($p = 0.000$), respectively. The average scores for women included in our analyses are 10.3 ($SD = 3.7$), 9.7 ($SD = 3.6$), and 9.7 ($SD = 3.8$) for *G*3 schooling attainment, *G*3 anthropometry at birth, and *G*3 36-month anthropometric Z-scores, respectively.

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[24] The strategy of using the combined indicator of women's cognitive skills rather than disaggregated components was dictated by the need to limit the number of right-hand-side variables in the IV estimates. In 1988-9, the respondents' abilities to read numbers and prices, order prices, and perform simple arithmetic calculations involving prices, salaries, and distances were also assessed. However, we do not use indicators of numeric ability in the present paper because they were not assessed in 2002-4, so we are not able to obtain estimates of scores at about age 18 for much of our sample using methods parallel to those that we use for the Raven's and IARC tests.

[25] Women's average age at first union is 19.8 years, and their average age at first parenting is 20.3 years (Behrman et al. 2006).

Maternal Reading-Comprehension Cognitive Skills

In 1988-9 and 2002-4, the vocabulary and reading-comprehension modules of the Inter-American Reading and Comprehension Tests (IARC, see Manuel 1967) were administered to the sample participants. In 2002-4, the vocabulary portion contained 45 questions and the reading comprehension portion contained 40 questions, yielding a maximum possible score of 85 points.[26] During both the 1988-9 and 2002-4 data rounds, sample participants were given a preliteracy screening test before taking the reading-comprehension test.[27] In 2002-4, 632 of the 777 women (81 percent) who participated in the preliteracy screen passed the screen and took the IARC. In 1988-9, 507 women took the IARC (74 percent of 683 women who participated in the preliteracy screen). The 19 percent and 26 percent of the sample who did not pass the preliteracy screen in 2002-4 and 1988-9, respectively, are assigned a value of zero for the reading-comprehension tests. Including those we score at zero, the mean score is 34.4 in 2002-4 and 31.6 in 1988-9, with SDs of 21.9 and 21.5, respectively, indicating substantial sample variation. The IARC tests demonstrated adequate within-year test-retest reliability (correlation coefficients of 0.87 and 0.85 for vocabulary and reading, respectively), and good internal consistency and validity for the 1988-9 data (Pollitt, Gorman, and Metallinos-Katasaras 1991; Pollitt et al. 1993). The correlation between the tests conducted in 1988-9 and 2002-4 in our sample of 551 women who took both tests is 0.82 ($p < 0.001$).

"Adult" reading comprehension scores closest to when each woman started to have children were constructed in a manner identical to that described above for Raven's scores. Again including those we score at zero, the mean "adult" reading comprehension score for women is 31.3 with SDs of 21.2 ($n = 909$). The correlations between this "adult" score and the 1988-9 and 2002-4 tests are 0.99 ($p = 0.000$) and 0.86 ($p = 0.000$), respectively. The average scores for women included in our analyses are 29.7 (SD = 21.6), 28.0 (SD = 20.9), and 27.8 (SD = 21.4) for *G*3 schooling attainment, *G*3 anthropometry at birth, and *G*3 36-month anthropometric Z-scores, respectively.

Women's Cognitive Skills

We combined the *G*2 maternal reading-comprehension (IARC) and nonverbal (Raven's) test scores, each expressed in percentile terms, to represent *G*2 women's cognitive skills. Because the importance of each of these two components may differ across children's outcomes, we selected weights that are most consistent with each *G*3's outcome in our preferred IV estimates. The weights are determined using coefficients on maternal IARC and Raven's scores from IV regressions in which both are included on the right side (along with maternal height) and treated as behaviorally-determined. Table 2 gives the means and SD for the *G*2 women's cognitive skills for the different samples, with the weights given in Note C of that table.

[26] In 1988-9, the vocabulary portion contained 40 questions and the reading comprehension portion contained 40 questions, yielding a maximum possible score of 80 points.

[27] Sample members who reported completing six or more grades of schooling were assumed to be literate. Respondents who reported having completed fewer than three grades of schooling, and those who reported three to five grades of schooling but could not correctly read the headline of a local newspaper article, were given a pre-literacy test that began with reading letters. They were considered literate if they passed the test with fewer than five errors out of 35 questions, the most difficult of which was reading a five-word sentence aloud.

APPENDIX B: SUPPLEMENTARY TABLES

Table B.1. Attrition probits (with 1 if in sample) to construct weights used for *G*3 schooling regressions (N = 1,162)

	Model 1	Model 2
*G*2 exposure to intervention		
From birth to 36 months	0.027	0.010
	0.57	*0.19*
From birth to 36 months × *Atole*	0.000	-0.006
	0.00	*-0.09*
*G*2 village of origin		
San Juan	0.041	0.040
	0.61	*0.59*
Conacaste	0.062	0.057
	1.08	*0.98*
Espíritu Santo	-0.080	-0.065
	-0.95	*-0.77*
*G*2 birth year	**-0.052**	**-0.050**
	-11.03	*-9.01*
Student-teacher ratio at age 7 for *G*2	-0.001	-0.001
	-0.43	*-0.40*
Number of grades available at age 7 for *G*2	**0.100**	**0.099**
	2.38	*2.30*
Availability of work in local markets at age 15 for *G*2	-0.011	-0.002
	-0.18	*-0.0*
*G*1 mother's schooling	**-0.021**	**-0.021**
	-1.90	*-1.87*
*G*1 household wealth index in 1975	**-0.052**	**-0.042**
	-2.87	*-2.24*
Missing *G*1 mother's schooling	**-0.405**	**-0.345**
	-6.77	*-4.57*
Missing *G*1 household wealth index in 1975	0.067	0.054
	1.33	*0.77*
*G*1 mother or father had died by *G*2 age 15	0.052	0.060
	0.78	*0.87*
*G*2 is twin	**-0.170**	**-0.173**
	-1.90	*-1.95*
*G*2 lived with both G1 mother and father in 1975		0.027
		0.49
G2 lived with both *G*1 mother and father in 1987		**-0.082**
		-1.98
*G*1 mother alive in 2002		**0.151**
		2.70
*G*1 father alive in 2002		0.024
		0.52
*G*1 mother NOT living in original village in 2002		**0.113**
		1.87
*G*1 father NOT living in original village in 2002		-0.054
		-0.98
*G*2 number of siblings in survey		-0.009
		-0.76
Whether any *G*2 sibling reinterviewed in 2002–4		**0.192**
		3.28
Chi^2 statistic on variables in model 2 only		30.34
		[< 0.01]
Model Chi^2 statistic	198.96	247.11
	[< 0.01]	[< 0.01]
Pseudo-R^2	0.15	0.17

Notes: Sample consists of all 1,162 *G*2 women who were exposed to the INCAP supplementation intervention between 1969 and 1977. Standard errors are calculated allowing for clustering at the mother level (StataCorp 2005). Derivatives evaluated at the mean (*dP/dx*) presented with the corresponding Z-statistics italicized and indicated in bold if significant at 10 percent. P-values are in brackets.

Table B.2. Attrition probits (with 1 if in sample) to construct weights used in *G*3 birth weight regressions (N = 1,162)

	Model 1	**Model 2**
*G*2 exposure to intervention		
From birth to 36 months	-0.024	-0.005
	-0.61	*-0.11*
From birth to 36 months × *Atole*	0.055	0.041
	1.00	*0.75*
*G*2 village of origin		
San Juan	-0.068	-0.053
	-1.26	*-0.96*
Conacaste	-0.002	0.003
	-0.04	*0.06*
Espíritu Santo	0.029	0.023
	0.38	*0.31*
*G*2 birth year	**-0.006**	**-0.008**
	-1.70	*-1.77*
Student-teacher ratio at age 7 for *G*2	0.001	0.001
	0.29	*0.35*
Number of grades available at age 7 for *G*2	0.008	0.021
	0.22	*0.57*
Availability of work in local markets at age 15 for *G*2	0.079	**0.087**
	1.47	*1.65*
*G*1 mother's schooling	-0.014	-0.014
	-1.53	*-1.54*
*G*1 father's schooling	0.001	0.001
	0.07	*0.18*
*G*1 household wealth index in 1975	**-0.036**	**-0.036**
	-2.43	*-2.46*
Missing *G*1 mother's schooling	**-0.201**	-0.126
	-2.56	*-1.31*
Missing *G*1 father's schooling	**-0.174**	**-0.131**
	-3.40	*-2.18*
Missing *G*1 household wealth index in 1975	**-0.135**	**-0.125**
	-2.87	*-2.19*
*G*1 mother or father had died by *G*2 age 15	0.069	0.098
	1.24	*1.57*
*G*2 is twin	**-0.109**	**-0.117**
	-1.70	*-1.90*
*G*2 lived with both *G*1 mother and father in 1975		-0.034
		-0.75
*G*2 lived with both *G*1 mother and father in 1987		**-0.079**
		-2.30
*G*1 mother alive in 2002		-0.014
		-0.33
*G*1 father alive in 2002		0.032
		0.83
*G*1 mother NOT living in original village in 2002		**-0.143**
		-3.00
*G*1 father NOT living in original village in 2002		**-0.103**
		-2.28
*G*2 number of siblings in survey		-0.009
		-1.01
Whether any *G*2 sibling re-interviewed in 2002–4		**0.111**
		2.25
Chi^2 statistic on variables in model 2 only		47.7
		[< 0.01]
Model Chi^2 statistic	92.8	139.7
	[< 0.01]	[< 0.01]
Pseudo-R^2	0.08	0.12

Notes: Sample consists of all 1,162 *G*2 women who were exposed to the INCAP supplementation intervention between 1969 and 1977. Standard errors are calculated allowing for clustering at the mother level (StataCorp 2005). Derivatives evaluated at the mean (*dP/dx*) presented with the corresponding Z-statistics italicized and indicated in bold if significant at 10 percent. P-values are in brackets.

Table B.3. Attrition probits (with 1 if in sample) to construct weights used in *G*3 36-month anthropometry regressions (N = 1,162)

	Model 1	Model 2
*G*2 exposure to intervention		
From birth to 36 months	-0.012	0.003
	-0.31	*0.08*
From birth to 36 months × *Atole*	0.054	0.039
	0.97	*0.74*
*G*2 village of origin		
San Juan	-0.057	-0.040
	-1.11	*-0.77*
Conacaste	-0.048	-0.044
	-1.09	*-1.02*
Espíritu Santo	0.076	0.075
	1.03	*1.03*
*G*2 birth year	0.003	0.002
	0.72	*0.38*
Student-teacher ratio at age 7 for *G*2	0.001	0.001
	0.36	*0.50*
Number of grades available at age 7 for *G*2	-0.012	0.002
	-0.34	*0.05*
Availability of work in local markets at age 15 for *G*2	**0.099**	**0.107**
	1.95	*2.18*
*G*1 mother's schooling	-0.007	-0.007
	-0.79	*-0.76*
*G*1 father's schooling	-0.005	-0.005
	-0.79	*-0.66*
*G*1 household wealth index in 1975	**-0.033**	**-0.030**
	-2.35	*-2.16*
Missing *G*1 mother's schooling	**-0.180**	-0.077
	-2.42	*-0.81*
Missing *G*1 father's schooling	**-0.170**	**-0.130**
	-3.68	*-2.47*
Missing *G*1 household wealth index in 1975	**-0.080**	-0.065
	-1.85	*-1.22*
*G*1 mother or father had died by *G*2 age 15	0.087	**0.122**
	1.48	*1.86*
*G*2 is twin	-0.031	-0.034
	-0.47	*-0.56*
*G*2 lived with both *G*1 mother and father in 1975		-0.023
		-0.51
*G*2 lived with both *G*1 mother and father in 1987		**-0.081**
		-2.39
*G*1 mother alive in 2002		0.029
		0.68
*G*1 father alive in 2002		0.012
		0.34
*G*1 mother NOT living in original village in 2002		**-0.125**
		-2.79
*G*1 father NOT living in original village in 2002		**-0.120**
		-2.78
*G*2 number of siblings in survey		-0.010
		-1.19
Whether any *G*2 sibling reinterviewed in 2002–4		**0.119**
		2.64
Chi^2 statistic on variables in model 2 only		57.6
		[< 0.01]
Model Chi^2 statistic	56.0	110.8
	[< 0.01]	[< 0.01]
Pseudo-R^2	0.067	0.119

Notes: Sample consists of all 1,162 *G*2 women who were exposed to the INCAP supplementation intervention between 1969 and 1977. Standard errors are calculated allowing for clustering at the mother level (StataCorp 2005). Derivatives evaluated at the mean (*dP/dx*) presented with the corresponding Z-statistics italicized and indicated in bold if significant at 10 percent. P-values are in brackets.

Table B.4. Determinants of *G*3 schooling[a]

Indicator of *G*2 intellectual capital	Maternal grades of schooling Coefficient	t	Maternal cognitive skills Coefficient	t
Panel 1. OLS: *G*2 intellectual capital stocks only				
*G*2 Intellectual capital	0.109	3.45***	0.013	3.96***
*G*3 Gender (1 = male)	0.292	1.66*	0.284	1.61
*G*3 Twin	-1.541	-3.12***	-1.595	-2.97***
F-test	7.76		8.27	
p-value	0.000		0.000	
Panel 2. OLS: *G*2 intellectual capital stocks and nutritional status				
*G*2 Intellectual capital	0.085	2.63***	0.010	2.86***
*G*2 Height (cm)	0.044	2.6***	0.041	2.33**
*G*3 Gender (1 = male)	0.294	1.67*	0.287	1.64
*G*3 Twin	-1.605	-3.26***	-1.643	-3.13***
F-test	7.18		7.69	
p-value	0.000		0.000	
Panel 3. IV: *G*2 intellectual capital stocks only				
*G*2 Intellectual capital	0.186	3.06***	0.030	3.3***
*G*3 Gender (1 = male)	0.235	1.38	0.306	1.76*
*G*3 Twin	-1.498	-3.17***	-1.660	-2.92***
F-test	6.45		6.20	
p-value	0.000		0.000	
Weak ID: Cragg Donald F-test	21.89		14.57	
Overid: Hansen J statistic p-value	0.162		0.330	
Panel 4. IV: *G*2 intellectual capital stocks and nutritional status				
*G*2 Intellectual capital	0.152	2.3**	0.020	1.78*
*G*2 Height (cm)	0.151	2.61***	0.104	1.48
*G*3 Gender (1=male)	0.329	1.84*	0.319	1.8*
*G*3 Twin	-1.756	-3.3***	-1.764	-3.14***
F-test	6.17		5.24	
p-value	0.000		0.000	
Weak ID: Cragg Donald F-test	6.79		3.93	
Overid: Hansen J statistic p-value	0.476		0.354	

Notes:
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.
[a] For *G*3, the difference in grades of schooling from age-cohort mean (positive if grades schooled > cohort mean). N = 1,175 with 484 mothers; estimates cluster on mothers.

Table B.5. Determinants of *G*3 anthropometry at birth

	Maternal grades of schooling				Maternal cognitive skills			
Indicator of *G*2 intellectual capital	**Birth weight (kg)**		**Birth length (cm)**		**Birth weight (kg)**		**Birth length (cm)**	
***G*3 human capital outcome**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**
Panel 1. OLS: *G*2 intellectual capital only								
*G*2 Intellectual capital	0.011	1.46	0.046	1.24	0.002	2.72***	0.009	1.96*
*G*3 Gender (1 = male)	0.048	1.07	0.637	2.91***	0.044	1.00	0.623	2.86***
*G*3 Twin	-0.660	-5.88***	-3.336	-4.22***	-0.672	-6.23***	-3.241	-4.13***
F-test	13.28		9.86		16.39		10.90	
p-value	0.000		0.000		0.000		0.000	
Panel 2. OLS: *G*2 intellectual capital and nutritional status								
*G*2 Intellectual capital	0.001	0.15	-0.003	-0.07	0.002	2.51**	0.006	1.33
*G*2 Height (cm)	0.019	3.35***	0.099	3.69***	0.019	3.48***	0.094	3.76***
*G*3 Gender (1 = male)	0.046	1.04	0.620	2.92***	0.044	1.01	0.617	2.91***
*G*3 Twin	-0.651	-5.32***	-3.467	-4.18	-0.654	-6.16***	-3.363	-4.21***
F-test	11.45		9.93		15.73		10.62	
p-value	0.000		0.000		0.000		0.000	
Panel 3. IV: *G*2 intellectual capital only								
*G*2 Intellectual capital	0.026	1.59	0.111	1.49	0.005	2.88***	0.018	1.92*
*G*3 Gender (1 = male)	0.056	1.36	0.710	3.61***	0.055	1.35	0.695	3.54***
*G*3 Twin	-0.643	-6.22***	-3.761	-5.28***	-0.662	-6.73***	-3.673	-5.22***
F-test	15.55		15.89		19.10		16.99	
p-value	0.000		0.000		0.000		0.000	
Weak ID: Cragg Donald F-test	13.77		13.14		10.74		11.00	
Overid: Hansen J statistic p-value	0.187		0.375		0.365		0.404	
Panel 4. IV: *G*2 Intellectual capital and nutritional status								
*G*2 Intellectual capital	0.009	0.60	0.070	0.96	0.004	2.35**	0.011	1.21
*G*2 Height (cm)	0.027	2.45**	0.086	1.88*	0.027	2.64***	0.079	1.55
*G*3 Gender (1 = male)	0.072	1.77*	0.760	3.97***	0.080	1.99**	0.735	3.82***
*G*3 Twin	-0.635	-5.22***	-3.801	-4.97***	-0.650	-7.4***	-3.767	-5.45***
F-test	9.84		11.48		18.62		13.65	
p-value	0.000		0.000		0.000		0.000	
Weak ID: Cragg Donald F-test	5.10		4.80		5.16		4.55	
Overid: Hansen J statistic p-value	0.296		0.388		0.609		0.387	

Notes:
For birth weight, n = 576 with 327 mothers. For birth length, n = 556 with 320 mothers. Estimates cluster on mothers.
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.

Table B.6. Determinants of G3 36-month anthropometric Z-scores

	Maternal grades of schooling						Maternal cognitive skills					
Indicator of *G*2 intellectual capital	**LAZ**		**WAZ**		**WLZ**		**LAZ**		**WAZ**		**WLZ**	
***G*3 human capital outcome**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**
Panel 1. OLS: *G*2 intellectual capital only												
G2 Intellectual capital	0.059	2.76***	0.039	1.87*	-0.003	-0.17	0.005	2.09**	0.007	2.97***	0.001	0.45
G3 Gender (1 = male)	-0.124	-1.13	-0.058	-0.53	-0.053	-0.53	-0.143	-1.29	-0.069	-0.62	-0.053	-0.53
G3 Twin	-0.197	-0.38	0.479	0.58	0.699	1.01	-0.240	-0.45	0.539	0.64	0.724	1.05
F-test	3.28		1.44		0.45		2.15		3.34		0.57	
p-value	0.021		0.232		0.714		0.095		0.020		0.633	
Panel 2. OLS: *G*2 intellectual capital and nutritional status												
G2 Intellectual capital	0.021	1.16	0.014	0.7	-0.001	-0.07	0.002	0.91	0.004	1.60	0.001	0.58
G2 Height (cm)	0.075	8.36***	0.050	4.94***	-0.003	-0.31	0.076	8.17***	0.047	4.64***	-0.005	-0.48
G3 Gender (1 = male)	-0.108	-1.09	-0.047	-0.44	-0.053	-0.53	-0.115	-1.15	-0.053	-0.49	-0.054	-0.54
G3 Twin	-0.526	-1.44	0.259	0.4	0.714	1.01	-0.543	-1.55	0.317	0.48	0.747	1.06
F-test	18.65		7.30		0.35		19.12		7.86		0.47	
p-value	0.000		0.000		0.841		0.000		0.000		0.760	
Panel 3. IV: *G*2 intellectual capital only												
G2 Intellectual capital	0.092	2.43**	0.091	2.44**	0.052	1.6	-0.002	-0.31	0.012	2.68***	0.007	1.98**
G3 Gender (1 = male)	-0.086	-0.87	-0.041	-0.39	-0.055	-0.58	-0.117	-1.20	-0.063	-0.60	-0.063	-0.68
G3 Twin	-0.408	-0.79	0.609	0.76	0.835	1.27	-0.392	-0.79	0.770	0.93	0.886	1.36
F-test	2.46		2.25		1.48		0.66		2.65		1.94	
p-value	0.063		0.082		0.221		0.577		0.049		0.124	
Weak ID: Cragg Donald F-test	9.00		9.00		9.00		6.53		5.60		5.31	
Overid: Hansen J statistic p-value	0.075		0.423		0.281		0.025		0.369		0.328	
Panel 4. IV: *G*2 intellectual capital and nutritional status												
G2 Intellectual capital	0.031	0.79	0.082	2.06**	0.054	1.55	-0.005	-1.07	0.010	1.83*	0.010	2.11**
G2 Height (cm)	0.088	3.21***	0.043	1.49	-0.006	-0.24	0.099	3.73***	0.034	1.08	-0.034	-1.07
G3 Gender (1 = male)	-0.123	-1.34	-0.052	-0.50	-0.057	-0.59	-0.119	-1.24	-0.065	-0.62	-0.092	-0.93
G3 Twin	-0.647	-1.63	0.379	0.62	0.859	1.18	-0.730	-1.84*	0.528	0.82	1.048	1.33
F-test	3.96		2.78		1.00		4.00		2.52		1.43	
p-value	0.004		0.027		0.405		0.004		0.042		0.224	
Weak ID: Cragg Donald F-test	3.69		3.69		3.69		3.83		3.15		2.75	
Overid: Hansen J statistic p-value	0.327		0.374		0.213		0.406		0.264		0.288	

Note:
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.

Table B.7. First-stage estimates for selected *G*3 outcomes: Endogenous *G*2 grades of schooling and *G*2 height

	*G*3 grades of schooling[a] (n = 1,175, mothers = 484)				*G*3 weight at birth (n = 576, mothers = 327)				*G*3 36-month LAZ (n = 459, mothers = 296)			
	*G*2 schooling		*G*2 height		*G*2 schooling		*G*2 height		*G*2 schooling		*G*2 height	
	Coefficient	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**
Included instruments												
*G*3 gender (1 = male)	-0.070	-0.37	0.126	0.35	0.012	0.05	0.131	0.25	0.278	1.11	0.320	0.49
*G*3 twin	0.085	0.11	1.859	0.97	-0.064	-0.12	1.162	0.50	-0.898	-2.14**	3.265	1.10
Excluded instruments												
*G*2 lived in communities at 0-36 months of age	-0.451	-1.08	-0.134	-0.15	-0.375	-0.95	-0.855	-0.91	-0.224	-0.49	-1.096	-1.16
*G*2 exposed to *Atole* at 0-36 months of age	1.046	1.93*	0.612	0.52	0.723	1.26	0.562	0.42	0.801	1.26	1.369	0.95
*G*2 born in San Juan	-0.960	-2.06**	-0.384	-0.41	-0.459	-0.83	0.405	0.30	-0.425	-0.69	-1.422	-0.78
*G*2 born in Conacaste	-0.939	-2.18**	1.448	1.59	-0.776	-1.70*	1.619	1.43	-0.719	-1.50	0.822	0.67
*G*2 born in Espiritu Santo	-0.269	-0.40	-1.489	-1.11	-0.543	-0.71	0.695	0.45	-0.586	-0.69	-0.724	-0.37
Student-teacher ratio in community when *G*2 was age 7	-0.032	-2.29**	-0.004	-0.13	-0.035	-2.00**	-0.053	-1.35	-0.035	-1.61	-0.004	-0.08
No. of grades available in community when *G*2 was age 7	0.144	0.55	-0.344	-0.55	0.236	0.74	-1.264	-1.65*	-0.093	-0.24	-0.577	-0.71
Good local job markets when *G*2 was 15	-0.984	-2.21**	-0.616	-0.63	-0.704	-1.22	1.414	1.16	-0.787	-1.19	0.125	0.07
*G*1 mothers' schooling	0.324	3.82***	0.394	2.19**	0.222	2.51**	0.603	2.39**	0.234	2.49**	0.814	2.90***
*G*1 fathers' schooling					0.250	3.06***	-0.081	-0.58	0.287	3.02***	-0.139	-0.94
*G*1 household wealth index in 1975	0.958	5.58***	0.915	2.86***	0.972	5.12***	0.799	2.19**	0.881	4.09***	0.314	0.76
Missing *G*1 mothers' schooling	2.342	2.4**	1.255	1.36	1.517	2.88***	-0.342	-0.13	0.648	0.87	-1.594	-0.92
Missing *G*1 fathers' schooling					-0.443	-0.57	-0.404	-0.28	-0.572	-0.63	2.239	1.78*
Missing *G*1 household wealth index in 1975	0.708	1.85*	-0.745	-1.11	0.991	1.71*	-1.828	-1.72*	0.941	1.60	-0.505	-0.50
Death of *G*1 mother or father before *G*2 reached age 15	-0.859	-1.93*	-0.055	-0.05	-1.088	-2.64***	-0.894	-0.65	-1.275	-2.84***	-2.094	-1.43
*G*2 birth year	0.038	1.09	0.061	0.83	-0.014	-0.38	0.174	2.08**	-0.006	-0.14	0.188	2.00**
*G*2 is a twin	0.519	0.47	-3.766	-2.53**	0.969	1.51	-2.389	-1.12	0.683	1.08	-2.155	-1.61
Tests of excluded instruments	**stat**	**p**	**stat**	**p**	**stat**	**p**	**stat**	**p**	**stat**	**p**	**stat**	**p**
F-test of excluded instruments	10.89	0.000	3.41	0.000	13.02	0.000	3.73	0.000	7.18	0.000	2.61	0.001
Partial R2 of excluded instruments	0.221		0.088		0.296		0.137		0.259		0.129	

Notes:
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.
[a] *G*3 difference in grades of schooling from age-cohort mean (positive if grades schooled > cohort mean).

Table B.8. First-stage results for selected *G*3 outcomes: Endogenous *G*2 cognitive skills and *G*2 height

	*G*3 grades of schooling[a] (n = 1,175, mothers = 484)				*G*3 weight at birth (n = 576, mothers = 327)				*G*3 36-month LAZ (n = 459, mothers = 296)			
	*G*2 cognitive skills		*G*2 height		*G*2 cognitive skills		*G*2 height		*G*2 cognitive skills		*G*2 height	
	Coefficient	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**
Included instruments												
*G*3 gender (1 = male)	0.912	0.55	0.126	0.35	2.415	1.06	0.131	0.25	3.455	1.55	0.320	0.49
*G*3 twin	5.520	0.82	1.859	0.97	8.719	0.69	1.162	0.50	-5.924	-0.54	3.265	1.10
Excluded instruments												
*G*2 lived in communities at 0-36 months of age	0.291	0.07	-0.134	-0.15	-4.476	-1.06	-0.855	-0.91	-2.654	-0.61	-1.096	-1.16
*G*2 exposed to *Atole* at 0-36 months of age	9.115	1.79*	0.612	0.52	5.071	0.84	0.562	0.42	2.505	0.43	1.369	0.95
*G*2 born in San Juan	-2.952	-0.64	-0.384	-0.41	-3.358	-0.60	0.405	0.30	-3.792	-0.75	-1.422	-0.78
*G*2 born in Conacaste	3.067	0.73	1.448	1.59	-1.220	-0.25	1.619	1.43	-1.153	-0.26	0.822	0.67
*G*2 born in Espiritu Santo	2.405	0.37	-1.489	-1.11	3.512	0.49	0.695	0.45	1.039	0.15	-0.724	-0.37
Student-teacher ratio in community when *G*2 was age 7	-0.336	-2.46**	-0.004	-0.13	-0.244	-1.67*	-0.053	-1.35	-0.219	-1.52	-0.004	-0.08
No. of grades available in community when *G*2 was age 7	-1.989	-0.65	-0.344	-0.55	3.837	1.01	-1.264	-1.65*	4.291	1.23	-0.577	-0.71
Good local job markets when *G*2 was 15	0.426	0.09	-0.616	-0.63	11.790	2.09**	1.414	1.16	6.039	1.08	0.125	0.07
*G*1 mothers' schooling	3.502	4.82***	0.394	2.19**	2.321	2.82***	0.603	2.39**	2.442	3.01***	0.814	2.90***
*G*1 fathers' schooling					0.423	0.61	-0.081	-0.58	1.120	1.47	-0.139	-0.94
*G*1 household wealth index in 1975	6.662	5.11***	0.915	2.86***	2.845	1.59	0.799	2.19**	2.207	1.22	0.314	0.76
Missing *G*1 mothers' schooling	13.624	2.05**	1.255	1.36	11.458	1.42	-0.342	-0.13	40.925	4.64***	-1.594	-0.92
Missing *G*1 fathers' schooling					-2.810	-0.43	-0.404	-0.28	-8.123	-1.39	2.239	1.78*
Missing *G*1 household wealth index in 1975	5.267	1.44	-0.745	-1.11	1.212	0.26	-1.828	-1.72*	2.487	0.60	-0.505	-0.50
Death of *G*1 mother or father before *G*2 reached age 15	-2.750	-0.65	-0.055	-0.05	1.721	0.31	-0.894	-0.65	-4.300	-0.85	-2.094	-1.43
*G*2 birth year	-0.528	-1.49	0.061	0.83	-2.571	-6.91***	0.174	2.08**	-2.155	-5.78***	0.188	2.00**
*G*2 is a twin	4.783	0.48	-3.766	-2.53**	1.529	0.15	-2.389	-1.12	-1.556	-0.19	-2.155	-1.61
Tests of excluded instruments	**stat**	**p**	**stat**	**p**	**stat**	**p**	**stat**	**p**	**stat**	**p**	**stat**	**p**
F-test of excluded instruments	8.19	0.000	3.41	0.000	8.44	0.000	3.73	0.000	5.47	0.000	2.61	0.001
Partial R2 of excluded instruments	0.159		0.088		0.247		0.137		0.202		0.129	

Notes:
*** significance at 0.01 level, ** at 0.05 level, * at 0.10 level.
[a] *G*3 difference in grades of schooling from age-cohort mean (positive if grades schooled > cohort mean).

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